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SHUTTLE REMOTE MANIPULATOR SYSTEM MISSION PREPARATION AND OPERATIONS

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Abstract

The pre-flight planning, analysis, procedures development, and operations support for the Space Transportation System (STS) payload deployment/retrieval missions utilizing the Shuttle Remote Manipulator System are summarized. Analysis of the normal operational loads and failure induced loads and motion are factored into all procedures. Both the astronaut flight crews and the Mission Control Center (MCC) flight control teams receive considerable training for standard and mission specific operations. The real-time flight control team activities are described.

1. Introduction

The Payload Deployment and Retrieval System (PDRS) is the 50 foot, 6 jointed robotic arm that is used during Shuttle missions primarily to deploy and retrieve payloads. The PDRS was developed by Canada (SPAR Aerospace Limited under contract to the National Research Council of Canada) through an international partnership agreement between our two countries. Three flight units are currently available and are manifested as required on Shuttle flights. NASA has flown the PDRS on 18 Shuttle flights to date, and the PDRS has been used to deploy or retrieve 14 payloads. Payload retrieval and payload servicing has also been accomplished by attaching astronauts to the end of the PDRS via a manipulator foot restraint. This paper first describes the Shuttle PDRS, then describes the mission preparation and mission operations related to the PDRS.

2. PDRS Description

The PDRS is a compilation of several specialized systems including the following:

- Remote Manipulator System (RMS) - The mechanical arm assembly itself, the end effector (the "hand" of the arm), and the crew interfaces (Display and Control Panel, hand controllers, and interfacing electronics). The mechanical arm has six joints, a pitch and yaw joint at the shoulder, an elbow pitch joint, and a pitch, yaw and roll joint at the wrist.

- Manipulator Positioning Mechanisms/Manipulator Retention Latches (MPM's/MRL's) - Attaches the RMS to the Orbiter longeron. Mechanism (MPM) "rolls" the RMS outboard after the payload bay doors are open, and releases (MRL) the arm prior to RMS activity. These same mechanisms also "roll" the RMS back in and latch it down for re-entry.
- Grapple Fixture - Attaches directly to the payload. Includes a grapple shaft which is captured or snared by the end effector, and a target to align the end effector to the grapple shaft during payload capture.
- Closed Circuit TV - Two cameras mounted on the RMS at the elbow and wrist joints. Monitors are located near the hand controllers.
- Software Control - Control loop algorithms, system health monitoring routines, data transfer routines, and caution and warning alarm generation resident in the on-board systems management orbiter general purpose computer. (The RMS is capable of operating without these software controls in a contingency mode.)

The RMS plus the MPM's/MRL's weighs approximately 1000 lbs. and is occasionally not flown on Shuttle missions for weight savings purposes.

There are several operating modes available for control of the RMS as follows:

- Software controlled modes:
 - Orbiter Unloaded - Multi-joint control via two 3-degrees-of-freedom hand controllers. The software joint rate limiting algorithm assumes an unloaded arm.
 - Orbiter Loaded - Similar to Orbiter Unloaded, but joint rate limiting algorithm uses payload specific mass properties constants.
 - End Effector - Similar to Orbiter Unloaded, but with a different coordinate system for control.
 - Payload - Similar to Orbiter Loaded, but with a different coordinate system for control.
 - Automatic Sequences - Complex pre-flight planned sequences and simple operator "fly-to" point designation are supported.
 - Single Joint Mode - Individual joints are driven by operator command through the Display and Control panel and routed through the RMS software.

- Hardware controlled modes:
 - Direct Drive - A contingency mode used to drive individual joints directly via hardware control, bypassing software control. The hardware in the RMS utilized by this mode is the same as used when under software control.
 - Backup Drive - Another contingency mode used to drive individual joints directly via hardware control, bypassing software control. Some of the hardware in the RMS utilized by this mode is different than that used by the Direct Drive or software control. Also, an alternate power source is used to power the RMS in this mode.

3. PDRS Operational Limitations

Payloads weighing up to 65,000 lbs. can be deployed by the RMS in a non-time-constrained operation. Most payloads to date have weighed less than 2000 lbs, with the Long Duration Exposure Facility (LDEF) being the heaviest at 21,000 lbs. Payloads weighing up to 32,000 lbs can be retrieved by the RMS. Again, most payloads have been much lighter than this. LDEF will be our heaviest payload to date to retrieve when we fly the STS-32 mission (November, 1989).

The RMS operator must have good visual cues both by observing the payload/RMS out the aft flight deck windows and via cameras. Often visual cues must be placed on the payload to enhance operations (such as berthing whiskers for LDEF). There must be sufficient clearance between all points on the payload and the Orbiter structure (at least 2 feet) during maneuvering by the RMS. The operator slows the rates at which the payload/RMS is maneuvered anytime the payload is within 5 feet of structure. Loads which may be induced on the payload or the RMS (RMS runaway failures, reaction control system jet firings, etc.) must be within the structural limitations of these systems.

4. Mission Preparation

The detailed deploy/retrieve procedures and analyses supporting those procedures begin in earnest approximately 2 years before the flight of a payload. Preliminary mission design and payload integration begins many years earlier. This mission design process ensures that payload unique constraints are accommodated while ensuring safe operational use of the RMS. Every payload which is to be deployed or retrieved has its own unique set of constraints which must be accommodated while on the RMS. For example, some payloads must be pointed away from the sun to prevent over-temperature, some must have their antennas pointed at communications satellites, special orientations must be developed to allow solar array/antenna deployment, etc.

The mission procedures must also consider clearances during normal RMS operations (2 foot minimum), and the Orbiter reaction control system and runaway induced loads and motion must be analyzed to ensure structural compatibility (and to

avoid contact between the payload and the Orbiter). If excessive loads or motion are determined, the deploy/retrieve operations can usually be modified to eliminate the problem.

Flight control systems stability must also be analyzed, and the Orbiter/RMS/payload configuration must be controllable via the digital auto pilot software and reaction control system jets.

Mission design and procedures development is accomplished by an assigned Mission Operations Directorate (MOD) mission designer, who is supported by a team which grows as the flight nears. Payload RMS reach and visibility studies are performed on graphics supported kinematic simulators executing on office workstations, and a preliminary deploy/retrieve scenario is developed. Dynamic loads and motion analyses are performed on non-graphics simulators, and the results used to iterate on the proposed operations.

As procedures mature, they are reviewed in higher fidelity simulators which include Orbiter payload bay plus RMS scene generation and crew interfaces. Often, the astronauts become involved at this stage of procedures development. Both normal and multiple contingency procedures are developed to work around any problems which may occur during the flight. The multiple control modes of the RMS are very useful for these contingency procedures. Validated procedures are documented in the flight data file checklists, and the appropriate RMS-trained crewmen are further trained for flight specific operations. Many simulations are conducted using the developed procedures. These include integrated simulations in which both the crewmen and the flight control team are trained and tested in the use of the procedures and in the systems capabilities and malfunction recognition/analysis/workaround.

5. Mission Operations

The astronauts are the operators of the RMS (no control from the ground) and are trained to follow the normal procedures, plus the multiple contingency procedures that are developed for every flight. Three PDRS Mission Control Center (MCC) operators man the consoles during all PDRS operations, monitoring the health and status of the systems. If PDRS failures occur during the flight, the crew performs the pre-flight developed malfunction procedures. Between these procedures, the crew observations, and analysis of the telemetry data by the PDRS console operators, the source and operational effect of the problem is determined. Additional detailed engineering support for the PDRS systems are provided by the NASA engineering community monitoring the flight from the Mission Evaluation Room (MER), and is available as needed.

Pre-flight developed operational workaround procedures for problems are utilized if appropriate, otherwise, real-time procedures are developed. Often, the RMS is used in a manner not predicted pre-flight, and real-time procedures must be developed. For

example, on STS 41-D, the RMS was used to knock off a large mass of ice that had formed on the side of the Orbiter when an overboard water vent became clogged and ice formed. All real-time developed procedures must be validated by compressing the mission design process (simulator and required support personnel are immediately available).

6. Closing Remarks

The PDRS is an extension of the crewman in the payload bay. It is an extremely flexible and valuable tool to the NASA space program. Operational procedures for using the RMS are either developed and validated pre-flight (for 2 years), or are developed and validated in real-time (real-time developed procedures are typically less complicated). Trained crewmen and trained console operators ensure that procedures are executed properly, and that problems are assessed and worked expeditiously. The PDRS will continue to support the deployment and retrieval of payloads, and will play a major role in the assembly and operations of Space Station Freedom.